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(54) Temperature stable circuit for recycling discharge current during the driving of an inductive load.

(57) A circuit for recycling the discharge current of an inductive load being driven, comprising an active semiconductor device (T) connected serially with the inductive load (L) between first and second terminals of a voltage supply source and having a control terminal for connection to a driver circuit means (C), and a control circuit means (R_1,R_2,COMP) connected between the inductive load and said control terminal.

The control circuit means comprises a voltage divider (R_1,R_2) connected between the inductive load (L) and the first terminal of the voltage supply source, and a comparator (COMP) having first and second input terminals respectively connected to the voltage divider and to a voltage reference and an output terminal which is coupled to the control terminal of the active element (T).

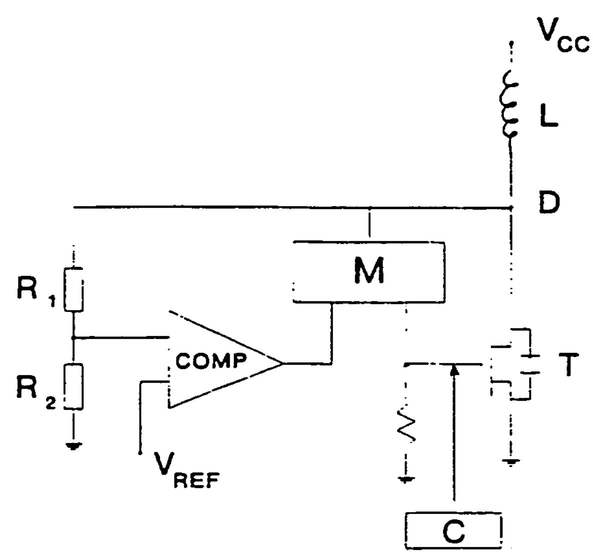

Fig. 2

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This invention relates to an electronic temperature stable circuit which is useful for current recycling while inductive loads are being driven, and particularly to such a circuit which is integrated monolithically.

Within the scope of this invention, the problems connected with inductive loads as used in motor vehicle fuel injection control devices will be considered by way of example.

In such devices, the driving of the current flow through an inductive load representing the injector allows to open and close the device.

In such a case, as the inductive load is being driven, it matters that the control current flowing through the load can be cut off within the shortest possible time, in order for the injector closing time to be made short and the amount of fuel injected accurately metered out.

It is recognized that, in general, the driving of inductive loads brings about some problems during the transients.

In fact, upon cutting off the current flowing through an inductor, a voltage surge (positive or negative overvoltage) occurs at the inductor.

That overvoltage is due to the induced electromotive force tending to clamp the current to the value attained during the "on" period, i.e. during the charging phase.

In the instance of fuel injection control in a motor car, as herein considered, the load has a terminal at a fixed supply potential, so that the potential increase will occur at the linking node to the driver circuit.

Accordingly, the amplitude of the voltage peaks at said node must be limited, since otherwise they may cause breakage of the junctions in the semiconductor elements provided within the driver or other circuits connected to that same inductive load.

In addition, with monolithically integrated circuits, such peaks may be a triggering cause of parasitic transistors.

A state-of-art approach provides for the introduction, between the driver circuit and the inductive load, of circuitry including power elements for the so-called recycling of discharge current from the load.

In that way, the energy stored within the inductive load can be dissipated: the voltage thereat, after attaining a predetermined maximum, will remain constant for a time and then drop back to zero along with the current, following full discharge through the power elements themselves.

The discharge time is dependent on the maximum voltage value attained at the inductor.

In such prior approaches, therefore, the recycle circuit is also to limit the voltage rise to a predetermined top value. This voltage limiting effect is referred to as clamping in technical literature.

Where the current quenching time through the inductive load requires to be accurately controlled, this is accomplished using a recycle circuit so dimensioned as to allow a suitable maximum voltage value to be selected, since, as mentioned, the duration of the discharge phase depends directly on the maximum voltage attained at the inductor upon turning off the driver circuit.

It is of special interest that the adjustment can be performed irrespective of outside conditions, in particular independently of temperature.

A standard approach has been heretofore to use, as the recycling power element, the same power transistor -- whether of the field-effect (usually MOS) type or the bipolar type --as is used for driving the load.

Auxiliary control circuit arrangements control the voltage value at the load and automatically turn on the power element upon that voltage attaining its predetermined maximum value.

Two main solutions are provided circuit-wise in the prior art.

A first one consists of connecting one or more Zener diodes between the control terminal of the driver power transistor and the inductive load.

That is, the Zener diodes are arranged to set a top voltage value VD at the inductive load, because as that set value --which is equal to the combined Zener voltages -- is exceeded, the diodes will begin to conduct, thereby enabling conduction through the transistor until the inductor is discharged.

A disadvantage of this prior circuit is that a top voltage value exactly equal to the desired one cannot always be obtained, because it would be dependent on the sum of the discrete Zener values, and optimum clamping cannot be achieved.

Furthermore, since the voltage drops across the Zener diodes and at the control terminal of the power transistor depend on temperature in different degrees, compensation can only be obtained for certain definite values of VD.

In an attempt to obviate such drawbacks, the second prior art solution provides a combination of diodes, Zener diodes, and transistors in the recycle circuit.

One of the last-mentioned circuit arrangements is depicted in Figure 1.

The circuit in Figure 1 operates as follows.

Upon the driver circuit C for the power element turning off the transistor T, an overvoltage is generated at node D. As this voltage reaches a value $V_D = V_Z + V_{BE} + V'_{BE} + V_{GS}$ (where, V_Z is the Zener voltage of Z_1, V_{BE} is the voltage drop between the base and the emitter of transistor T_1, V'_{BE} is the voltage across diode D_1, and V_{GS} is the voltage drop between the gate and the source of transistor

T when this is a field-effect transistor), the Zener diode begins to conduct, causing the transistor T to be turned back on.

Thus, current recycling from the inductive load is started.

It should be noted that Z_1, T_1 and D_1 in the Figure may represent a number N of Zener diodes, transistors and diodes connected in series, whereby V_D is the result of several potential drops combined.

In that way the discharge time of the inductive load can be optimized.

That circuit has, however, a disadvantage in that the voltage value at the node D is truly stable neither as temperature changes nor for each selected value of VD, although it is stabler through a broader temperature range than the previously mentioned conventional solution.

It is an object of this invention to provide a current-recycling circuit whose stability is unaffected by temperature.

A further object is to arrange for said temperature-wise stable feature to be retained as the maximum voltage value at any inductive load varies.

The invention and its advantages are more clearly illustrated by the accompanying drawings, in which:

- Figure 1 is a diagram of a prior art circuit for recycling current while an inductive load is being driven, whose operation has been discussed hereinabove; and
- Figure 2 is a diagram of a circuit for recycling current while an inductive load is being driven, according to this invention.

In either drawing figures, L denotes the inductive load, Vcc the voltage supply, and T the transistor through which the current recycling is performed.

This transistor is shown as a field-effect transistor, but may be a bipolar type, in accordance with the prior art.

In addition, the transistor T would normally be a power transistor.

Also shown is a driver circuit means as schematically indicated in block form at C.

D denotes the connection node between the inductive load, the current recycle control circuit, and the transistor T.

The circuit diagram in Figure 2 is one embodiment of this invention, further comprising a current mirror M, a comparator COMP, a voltage reference V_{REF}, and two resistors R_1 and R_2 forming a voltage divider.

The transistor T is connected in series with the inductive load L between ground and a terminal of a supply voltage source Vcc.

Connected to the control terminal T are a driver circuit means C and a control circuit which is also connected to the inductive load.

The control circuit is operative to determine the mode of turning the transistor T back on while allowing current to be recycled from the inductive load through T.

This control circuit comprises, in the example shown, the voltage divider R_1, R_2 connected between the inductive load and ground, the comparator COMP, and the current mirror M.

The comparator COMP has two input terminals connected to the divider and the voltage reference V_{REF}.

The current mirror M has an input leg connected to an output terminal of the comparator and an output leg connected to the control terminal of the transistor T, and feeds into the node D.

The circuit of this invention operates as follows.

In a similar manner to the conventional circuit shown in Figure 1, the transistor T is turned on again for current recycling depending to the voltage value at the node D.

Upon that voltage attaining a predetermined value $V_D = V_{REF}(R_1 + R_2)/R_2$, which also represents the comparator threshold, the comparator will output a signal causing the transistor to be turned on again.

Thus, current recycling is triggered from the inductive load L to clamp the voltage at node D to the value V_D.

The transistor T is held in the "on" state until all of the inductive load energy is discharged. The choice of V_D isobtained at once by suitably proportioning the divider ratio $(R_1 + R_2)/R_2$. (Of course, each of the resistors R_1 and R_2 shown in Figure 2 may represent a number N of resistors).

This recycle circuit is highly stable temperature-wise because the temperature variation of V_D is only dependent on the voltage reference VREF, which can be selected to be temperature stable.

This reference can be expediently provided using, for example, a Wildar device known as bandgap.

It should be noted that V_{REF} may be either positive or negative.

The current mirror allows a current to be supplied which may be amplified, if desired.

However, it is not essential to the invention, and other circuit elements may be used to have the transistor turned on.

It should be considered that where the voltage at node D attains a high value in operation, the resistor R_1 and current mirror, being connected to that node, are required to operate at a high voltage.

The current-recycling circuit just described has the advantage of being substantially stable temperature-wise by virtue of the voltage control being implemented by a divider and a voltage reference being used.

Furthermore, any value may be selected for the voltage V_D by appropriate variation of the resistive divider. The current-recycling transistor T shown by way of example may be replaced with another active element, such as a Darlington, effective to drive the inductive load and recycle its discharge current.

The voltage divider may be implemented in any desired way without impairing its effectiveness.

The current mirror, which in this example feeds into the node D for convenience, could alternatively be supplied another potential.

Instead of the low-side driver configuration shown in Figure 2, with the power transistor arranged to drive the load to the supply, the circuit could be a high-side driver configuration with the load being driven to ground by the power transistor.

It will be appreciated that many modifications, adaptations, integrations, variations, and substitutions with other equivalent elements may be made onto the embodiment described hereinabove by way of non-limitative example without departing from the protection scope of the appended claims.

Claims

1. A circuit for recycling the discharge current of an inductive load while it is being driven, comprising an active semiconductor device (T) having first and second terminals whereby it is connected in series with the inductive load (L) between first and second terminals of a voltage supply source and a control terminal for connection to a driver circuit means (C), and a control circuit means (R_1,R_2,COMP) connected between the inductive load and the control terminal of the active element, characterized in that said control circuit means comprises a voltage divider (R_1,R_2) connected between the inductive load (L) and the first terminal of the supply voltage source, and a comparator (COMP) having first and second input terminals respectively connected to the voltage divider and to a voltage reference, and an output terminal coupled to the control terminal of the active element (T).

2. A circuit according to Claim 1, characterized in that it comprises a current mirror circuit having an input leg connected to the output terminal of the comparator and an output leg connected to the control terminal of the active element.

3. A circuit according to Claim 2, characterized in that the current mirror has a supply terminal connected to the inductive load.

4. A circuit according to any of the preceding claims, characterized in that the voltage reference is provided by a Wildar device.

5. A circuit according to any of the preceding claims, characterized in that the active element is a power transistor, and that the first and second terminals and the control terminal are a source terminal, drain terminal, and gate terminal, respectively.

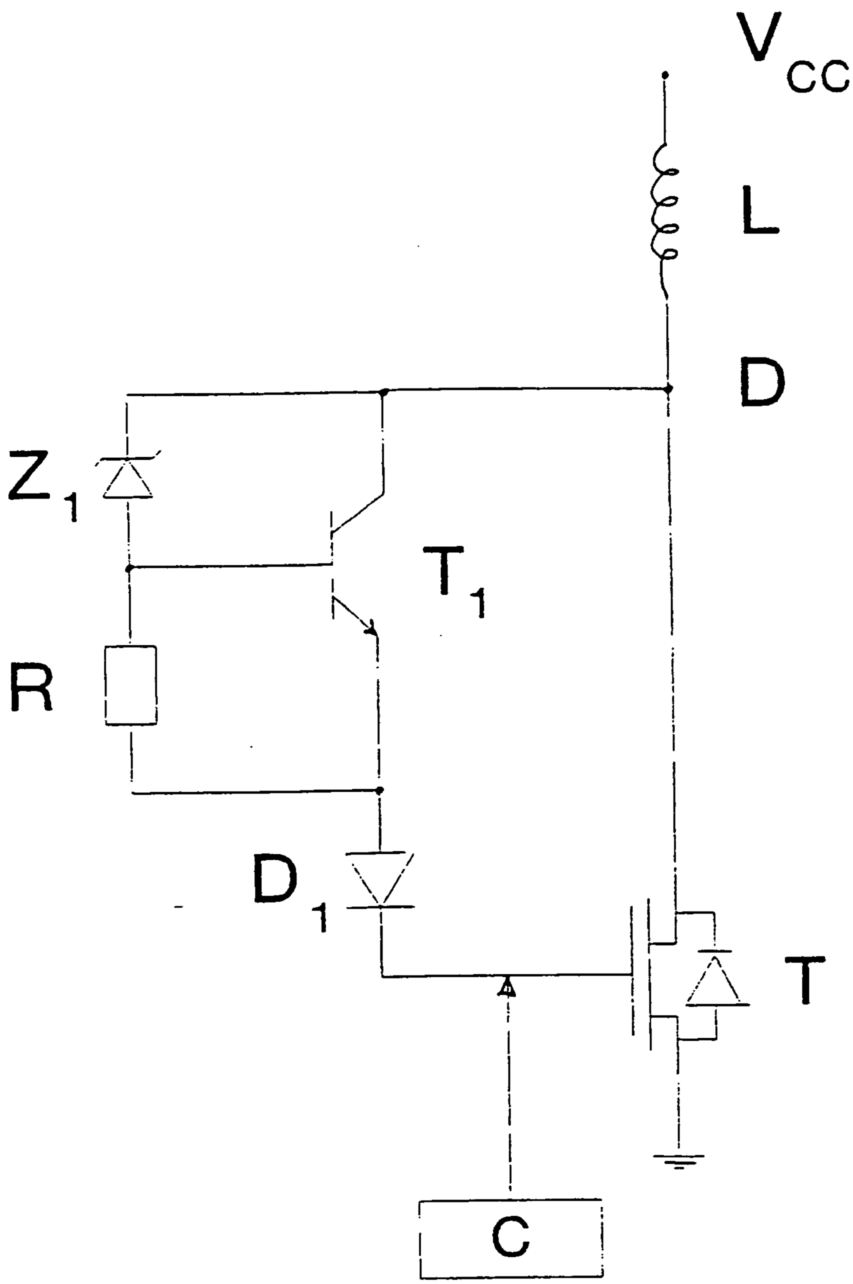

Fig. 1

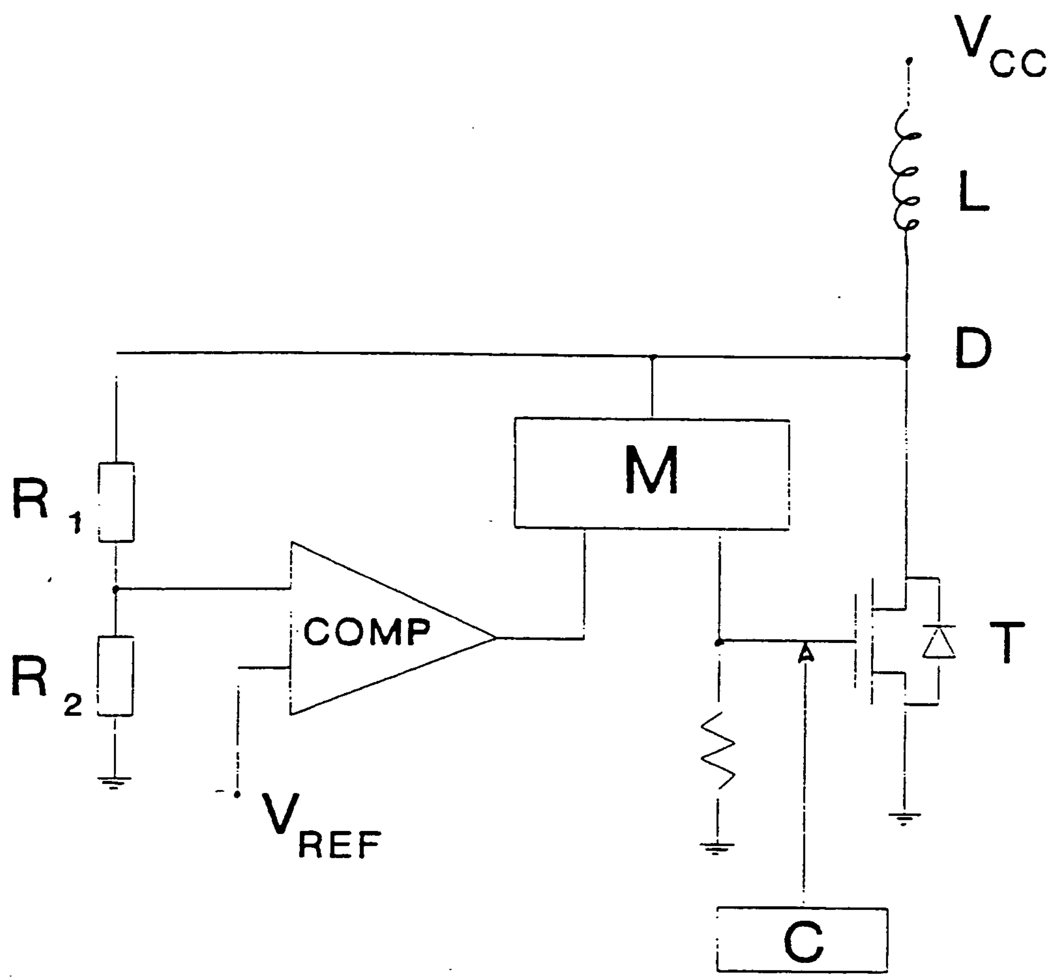

Fig. 2

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EUROPEAN SEARCH REPORT

Application Number

EP 93 83 0189

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X	US-A-4 860 152 (D. OSBORN) * column 2, line 51 - column 3, line 5 * * column 3, line 18 - column 4, line 45; figure 2 * ---	1,2,5	G05F1/00 H03K17/08 H03K17/16
A	FR-A-2 593 946 (AUTOMOBILES PEUGEOT-CITROEN) * page 2, line 31 - page 5, line 27; figure 1 * ---	1-3,5	
A	EP-A-0 399 754 (MOTOROLA INC.) * column 6, line 50 - column 8, line 17; figure 1 * ---	1	
A	EP-A-0 159 233 (THOMSON-CSF) * figure 1 * ---	1,2	
A	US-A-4 287 436 (HIDEHARU TEZUKA ET. AL.) * column 2, line 59 - column 4, line 68; figure 1 * -----	1	

TECHNICAL FIELDS SEARCHED (Int. Cl.5)

H03K

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	26 OCTOBER 1993	BUTLER N.A.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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